The National Aerospace Initiative (NAI): Technologies For Responsive Space Access

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Abstract

The Secretary of Defense has set new goals for the Department of Defense (DOD) to transform our nation's military forces. The Director for Defense Research and Engineering (DDR&E) has responded to this challenge by defining and sponsoring a transformational initiative in Science and Technology (S&T) – the National Aerospace Initiative (NAI) - which will have a fundamental impact on our nation's military capabilities and on the aerospace industry in general. The NAI is planned as a joint effort among the tri-services, DOD agencies and National Aeronautics and Space Administration (NASA). It is comprised of three major focus areas or pillars: 1) High Speed/ Hypersonics (HSH), 2) Space Access (SA), and 3) Space Technology (ST). This paper addresses the Space Access pillar. The NAI-SA team has employed a unique approach to identifying critical technologies and demonstrations for satisfying both military and civilian space access capabilities needed in the future. For planning and implementation purposes the NAI-SA is divided into five technology subsystem areas: Airframe, Propulsion, Flight Subsystems, Operations and Payloads. Detailed technology roadmaps were developed under each subsystem area using a time-phased, goal oriented approach that provides critical space access capabilities in a timely manner and involves subsystem ground and flight demonstrations. This S&T plan addresses near-term (2009), mid-term (2016), and long-term (2025) goals and objectives for space access. In addition, system engineering and integration approach was used to make sure that the plan addresses the requirements of the end users. This paper describes in some detail the technologies in NAI-Space Access pillar. Some areas of emphasis are: high temperature materials, thermal protection systems, long life, lightweight, highly efficient airframes, metallic and composite cryotanks, advanced liquid rocket engines, integrated vehicle health monitoring and management, highly operable systems and payloads. Implementation strategies for NAI is also described.

Introduction

The NAI is a technology initiative to assure the U.S. leadership in aerospace in the coming years. Recent studies by NASA, DOD and the Commission on the Future of Aerospace Industry (references 1-4) stress the need for an improved aerospace technology base for the country. A national leadership is needed to elevate space on the national security agenda and to recommend a space policy to transform the military into a viable space force by promoting both government and commercial investment in leading edge technologies to assure that the U. S. has the means to master operations in space and compete in international markets. Investments in science and technology resources- both facilities and people- are essential. It is important to create and sustain a cadre of space professionals, and provide resources and direction to ensure that advances in space technology continue. The U. S. Government should play an active, deliberate role in expanding the pool of military and civilian talent in science, engineering and systems operation that the nation will need. NAI will provide the investments needed in science and technology that will help to meet that national goal.

NASA strategic plan requires new space transportation capabilities to ensure America's leadership in space and also for purposes of education, science and commercial competitiveness. NASA's Space Launch Initiative (SLI) supports exploration of the universe and search for life by ensuring safe, affordable and reliable access to space. NASA is committed to developing an alternate (to the Space Shuttle) access to the International Space Station and a heavy launch capability for space exploration. NASA has plans for significant investments in developing the next generation launch technologies (NGLT). Commonality exists between NASA and DOD technology needs.

Significant synergies can be achieved by integrating the technology plans of NASA and DoD and executing them jointly. The NAI – Space Access technology planning is a joint DOD-NASA activity that is national in scope. It integrates the technology development and demonstration work of Tri-Services, DoD agencies and NASA. This paper describes the process used to develop the joint NAI technology program, a brief summary of the technology plans for space access, and strategies for implementing them.

Technology Planning Process

The NAI is planned in three major technology areas or pillars: 1) High Speed Hypersonics (HSH), 2) Space Access (SA) and 3) Space Technology (ST), see Figure 1. Figure 1 also lists the major technologies pursued by the NAI and the capabilities it will develop. HSH and ST are covered by other papers and are not described here. It should be noted, however, that significant synergy exists between space and hypersonic technologies, when combined with space access technology plan, enables an overall military space plane (MSP) architecture, including responsive payloads, and NASA's future generation of launch vehicles. NAI has a twenty+ year plan that matures key technologies in three distinct phases-- near term (Phase 1), midterm (Phase 2), and far term (Phase 3), shown notionally in Figure 2. Previous Air Force studies and requirements (Reference 2) and the NASA strategic plan (Reference 6) form the basis to identify Phase 1, 2 and 3, launch system goals. At the completion of each phase the technologies developed will be transitioned to support a follow-on Air Force Space Command (AFSPC) acquisition program for a launch system for the MSP and/or NASA's acquisition of future generation launch vehicles. Within the SA technology portfolio are near and mid term rocket based systems for space access, hypersonic technology for far term systems, and responsive payload technologies required for an MSP architecture. The goals were identified as technology stretch goals to ensure that the relevant supporting technologies are maturated as aggressively as possible, consistent with AFSPC and NASA requirements. The phase completion dates shown signify when the technology base will be sufficient to enable a system with these identified requirements. These are not system IOC (initial operating capability) dates.

A planning team called the Technology and Experiments Advisory Committee (TEAC) was assembled with members from both DOD (Tri-services and DARPA) and NASA, covering all relevant technology areas. Several panels were created to address the specific technology areas: *Airframe, Propulsion, Vehicle Subsystems, Operations, Payloads, Systems Engineering & IVHM and Integrated Technology Demonstrators* (see Figure 3). The panel members are experts in their fields and they assessed the technology state of the art in these key areas relative to space access and developed road maps showing the technologies that need to be developed and maturated to achieve the goals in phases. Each key area is broken down into component technology goals, objectives, technical challenges and approaches (GOTCHA's). An example is shown in Figure 4 for Airframe. Much of this technology will be matured in ground demonstration programs to TRL – 6 and selected technologies will be flight tested and demonstrated. Progress will be assessed against quantifiable and measurable goals identified as a part of the NAI plan. The panel outputs are integrated and prioritized by a steering committee (part of TEAC) consisting of senior members of both NASA and DOD. In addition, a senior advisory panel was utilized to make sure that the output of the planning team was fully integrated and met the top-level requirements of the agencies and services.

Technology Plans

As mentioned before, GOTCHA process was used to develop technology programs and metrics. Each technology area has a set of goals and objectives, which can only be attained by overcoming considerable technology challenges that require well thought-out approaches to overcome barriers and deliver the advanced technologies. Each technology area is discussed in some detail.

Airframe Technologies

The airframe technology taxonomy includes Propellant Tanks, Integrated Structures, Thermal Protection Systems (TPS), and Design and Analysis Tools (illustrated in Figure 3). The specific component technologies addressed in Phase 1 are shown in the GOTCHA chart (Figure 4). The phased system goals for each of the first two phases of the NAI-SA are shown in Table 1 for airframe technologies. Advanced technologies are pursued in the following areas:
Integrated structures-

- Integration – Integrated airframe, TPS/tank integration concept, establish figures of merit
- Integrated thermal structures -functionally graded and hybrid concepts incorporating carbon and/or ceramic foams, tiles, etc.
- Control surfaces - refractory composites – C/C or C/SiC, high temperature metallic – gamma TiAl
- High temperature primary structure - high temperature PMC and metallic alloys, insulated structures
- Actively cooled structures - actively cooled CMC acreage structures

- Sensors – high temperature fiber optic sensors for IVHM and ground test applications

Propellant tanks-

- Organic matrix composite (OMC) cryogenic tanks --develop fracture control philosophy
- Metallic -- Al-Li – L277, C458, 2195 processing and fabrication, friction stir welding, expendable
- Cryo-insulation – foams, honeycomb, bonded panel, stand-off panel—optimized for reusability and system weight savings, material development
- Fully integrated structural tanks – innovative designs and joining methodologies
- Advanced metallic materials development – high Li alloys, metallic foams

Thermal Protection System (TPS)-

- Leading edges – blunt, sharp—refractory composite (C/C or C/SiC); cooled leading edge—heat pipe cooled and actively cooled (composite, ceramic or metallic)
- Control surface materials – hot structures (C/C, C/SiC), insulated structures, functionally graded hybrid incorporating carbon or ceramic foams, tiles.
- Acreage – leeward, windward – high temperature metals (ODS, super alloys, TiAl, coatings, advanced joining, corrosion, durability), CMCs—fiber and matrix development, oxidation protection system
- Seals – for control surfaces, acreage TPS, leading edge; thermal barriers/penetrations, TPS panels, environmental pressure seals

Design and Analysis Tools-

- Aero-sciences (covered under *Systems Engineering and Integration*)
- Structures and materials

In addition, advancement in and manufacturing technologies to reduce cost are included in the plan.

Propulsion Technologies

Rocket propulsion focuses on technologies for liquid oxygen (LOX)/Hydrogen and LOX/Hydrocarbon rocket engines in the near and mid-term and looks towards merging rocket and air breathing technologies (from the HSH pillar) in the far term. Two-stage-to-orbit (TSTO) reusable system attributes are the top-level requirements used to identify top-level rocket subsystem goals shown in Table 2A. It should be noted that the IHPRPT (Integrated High Pay-off Rocket Propulsion Technology) program provides an immediate pay-off to NAI-SA and so does NASA's NGLT program. Both programs are being integrated into NAI. A good example is the Integrated Powerhead Demonstrator (IPD) that was initiated by IHPRPT and now jointly executed by the Air Force Research laboratory (AFRL) and NASA. The IPD is expected to demonstrate an overall cost reduction of 60% over the Space Shuttle Main Engine (SSME).

The top-level goals are broken down into component level objectives for each of the four taxonomies:
Propellants – fuels, oxidizers
Propellant management devices – turbo pumps, engine lines, ducts and valves
Combustion and energy conversion devices – chambers, nozzles, injectors, gas generators, and pre-burners
Controls: -- sensors, health management, software, engine controller
Propulsion component taxonomy objectives are shown in Table 2B and the goals for propulsion systems for different phases are shown in Table 2C for hydrogen and hydrocarbon boost. Approach and goals/objectives for the propulsion technologies are given below.

Hydrocarbon Rocket Technology

Approach:

- Develop prototype engine as test bed for phase 1 technologies (oxygen-rich staged combustion cycle)
- Maintain alternative technology development tasks to supplement engine prototype project
- Perform materials development tasks
- Enhance modeling, simulation and analysis capabilities
- Develop technologies to support next generation hydrocarbon rocket engine for phase 2

Goals/Objectives:

- Demonstrate oxygen-rich staged combustion cycle
- Characterize hydrocarbon fuels for proposed environments
- Demonstrate component-level use of new materials
- Enable designs for long life and reliability
- Design in adequate health management
- Reduce operations required for engine maintenance

Hydrogen Rocket Technology
Approach:
- Continue IPD program as a test bed for hydrogen engine technologies
- Develop hydrogen prototype as risk mitigator for new hydrogen engine
- Maintain alternative technology risk mitigation tasks to supplement engine prototype project
- Perform materials development tasks
- Enhance modeling, simulation and analysis capabilities
- Work technology development for upper (second) stage engine

Goals/Objectives:
- Demonstrate full flow staged combustion cycle
- Enable designs for long-life and high reliability
- Design in adequate health management
- Reduce operations required for engine maintenance
- Anchor analytical models

RCS/APS Technology
Approach:
- Emphasize development of leading non-toxic OMS/RCS technologies
- Develop LOX and GOX based thrusters in range of size classes
- Develop LOX acquisition technology
- Demonstrate feasibility of cryogenic RCS storage and distribution
- Develop LOX gasification and compression technology to enable use of GOX thrusters where LOX operation is not feasible

Goals/objectives:
- Eliminate need for serial processing (to allow other ground processes to occur in parallel)
- Eliminate toxicity hazards for ground servicing personnel
- Reduce ground maintenance and inspection to be consistent with 7-day turnaround
- Provide OMS/RCS performance comparable to existing technologies with minimum mass and reliability penalties

Main Propulsion System technology
Approach:
- Re-activate MPS component vendors and develop/test improved, reliable feed system and pneumatic components
- Develop/test cross feed components and system technology for performance improvements
- Initiate development of high reliability, high life cycle composite MPS lines and components
- Test & evaluate integrated MPS performance for component reliability and operability goals

Goals/Objectives:
- Increase reliability – MTBF >3000 hrs; catastrophic failures – 1 in 2000 launches
- Reduce costs -- # of maintainers – 20 MH/flt; marginal cost per sortie -- $ tens-Thousands
- Reduce weight – 10% from STS
- Increase operations – reduce turn time to 7 days; increase launch life to 100 launches

Rocket Based Combined Cycle (RBCC), scramjet and turbine technologies are covered under the HSH pillar.

Flight Subsystems Technologies
The focus of Flight Subsystems Technology plan is to research, develop, and demonstrate critical flight systems necessary to achieve future responsive, launch systems (both reusable and expendable) requirements as determined by the systems architecture for the war fighter and other space access needs. The Flight Subsystem taxonomy has six flight critical component technology areas for investment:

1. Power generation, distribution, management and control – Li-Ion batteries, flywheels, fuel cells, distribution, APU's
2. Actuation for engine thrust vector and aero-surface control, -- EMAs, EHAs, RCS
3. Vehicle management system (VMS- Avionics) technologies for flight and sensor data acquisition, dissemination, manipulation, computation and bussing and control – high speed processors, optical data links, advanced VMS, S/W V&V (validation and verification)
4. Thermal cooling systems for local and distributed power and control systems – fault tolerant heat exchangers
5. Integrated vehicle health management (IVHM) to monitor, diagnose, prognosticate and maintain these components – software, sensors, V&V

6. Flight mechanics to control, navigate and guide the vehicle autonomously throughout its flight and mission profiles – adaptive GN&C, rapid mission planning, V&V

A key distinction between civil/commercial and military reusable space access is the military requirement for a responsive capability (aircraft-like operations) and requires substantial science and technology push beyond the NASA STS operations. Past studies by AFRL and NASA have identified several subsystem investments required to achieve these goals: elimination of hazardous fluids (hydraulics), improving component reliability, improving subsystem built-in-test and health monitoring, reducing the number of maintenance personnel (or maintenance man hours per flight), reducing the number of active systems to maintain safe flight, and reducing the number of systems requiring ground servicing between flights. The subsystem goals are listed in Table 3, using shuttle as baseline system. A list of technologies being pursued is given below.

Generation and storage components (fuel cells, batteries, generators)
- Eliminate central hydraulics
- Increase KVA/lb
- Reduce system complexity, improve system efficiency and life
- Reduce maintenance manpower

Distribution components (capacitors, integrated power modules & power drivers, photonic controlled power modules)
- Fault tolerant power delivery – photonic fault tolerant power control, prognostics-based power management
- High voltage control and protection
- Distributed power architecture
- Thermal conditioning

Actuation components (brakes/steering, landing gear, aero-surfaces, thrust vectors/RCS)
- Utilize electric power
- Increase component reliability
- Line replaceable units
- Photonic controlled actuation
- Deceased weight (<HP/lb)
- Prognostics-based health management
- Smart material-based effectors

Vehicle Management system (polymeric wave guide, multi-fiber connector)
- Utilize commercial off the shelf
- Bus integrated architecture
- Robust, efficient electronics
- Photonically integrated architecture
- Radiation/temp hardened
- Drastically reduced weight (no wires)
- Improved reliability

IVHM
- Hierarchical diagnostics
- Reduced "Cannot Duplicates"
- Reduced maintenance time
- Component health monitors
- Active real time compensation
- Deferred maintenance—improve reliability
- Failure prediction/autonomous prognosis
- Virtual TO's-maintenance procedures

GN&C
- Adapt/compensate for control system faults
- Process tools for GNC design and validation
- Autonomous adaptive guidance control
- Real time trajectory control
- Abort contingency management
- "Turn the Crank" rapid mission planning
- Rapid response/quick turn V&V

Subsystem concepts need to be demonstrated on ground where possible and then in flight, and verified for operability, reliability and safety. Demonstration concepts have been developed. For examples, TVC aero surface actuation and power generation systems can be tested and verified through an integrated power-by wire component ground demo. Similarly, advanced VMS-IVHM development and adaptive GN&C can be verified by an integrated flight control component ground demo. Many or all of the advanced technologies will be combined and tested in a suitable flight demonstrator, such as X-42 (ref. 7).

Operations Technologies

Operations technology goals are to shorten time and reduce manpower for space launch operations. The overall goals of SA technologies are to reduce the turn around time to 7 days while reducing the marginal sortie cost to $10M in phase I, and to one day and $5M, respectively, in Phase II. Detailed analysis of shuttle operations and operations of several large aircraft resulted in the identification of six areas that need improvement. Table 4 lists these thrust areas along with improvements needed in each. Some details are given below.

Propellant Handling and Storage: More efficient and reliable cryogenic storage techniques are needed to support rapid response and multiple launches than those used today for low rate, launch on schedule operations. These techniques include better insulation and other thermal/vapor loss advancements as well as simplified and reliable servicing systems. The pay-offs include reduced personnel exposure during cryogenic conditioning operations and on-demand availability of conditioned propellant.
Flight Propellant Management Systems: New instrumentation technologies and techniques will be required to provide continuous feed back on the state of cryogenic propellants during the vehicle servicing process. Capacitive flow sensors have shown promise and need further development and testing.
System Assembly needs rapid movement, assembly, mate and rotation. Techniques and technologies to rapidly secure and move the vehicle will be evaluated. These include automated mating and assembly, component sensing and locating, and rapid ground power connections. Horizontal and vertical assembly, mating and erection will be explored to determine the best approach. Hazardous pyrotechnics will be eliminated. Common fluids for propulsion and power will be used with single point refueling and wireless communication with flight vehicles.
Launch Pad Operations: Launch exhaust management systems need better capability to suppress the acoustic energy generated during launch. Water deluge system used today is expensive to maintain and hazardous to the environment. A better understanding of the launch acoustic environment and modeling capability is needed to investigate the impact of different vehicle architectures on the acoustic environment.
System Refurbishment is a major area where advanced technologies can save significant costs. The following is a short list of technologies that will be pursued under NAI.
Advanced IVHM Sensors and Electronics Development: The demand for rapid launch facility refurbishment, greater launch processing automation and more reliance on "intelligent" ground systems require reliable system health monitoring and informed maintenance concepts. Areas to be addressed are prognostics, sensor development, and data integration. Advanced sensors, instrumentation and software algorithms with higher reliability and longer calibration cycles (3x or more) capable of interfacing with the IVHM systems will be developed. These products will automatically and autonomously perform self-calibration, health self checks, self-repair and self-reconfiguration to maintain operational capability with minimal or no human intervention. The technologies include multi-discipline, multi array non-invasive sensing, advanced data acquisition and wireless communication. The technologies developed will be integrated, functionally checked and tested under relevant environmental conditions. The pay-offs include increased reliability, safety, operability, responsiveness and affordability.
Hazardous gas and leak detection: The vision is that both point sensors and scanning mass spectrometers will be developed to provide the resolution and reliability needed for on-board systems. Technology development is needed in miniaturization of mass spectrometers and point sensors for enclosed areas such as pipes and broad area sensors for external leak visualization.
Intelligent Instrumentation and Inspection system: The near term activity in this area will be to work on developing candidate sensors suites that can support inspections of launch vehicles regardless of specific system concept. Ways to automate these inspections will also be developed. Technologies to investigate include: high dynamic range sensors, flexible sensors, multi-sensors and sensor fusion sets, flexible, self-calibrating instrumentation, shared criteria data base and networked instrumentation with common knowledge sets. It is envisioned that on-board IVHM systems will provide much of the information now requiring manual inspection.
Smart Umbilical Development: For cost effectiveness and high operational tempos new "smart" umbilicals are needed, which know when they are properly connected, and provide automatic verification prior to flowing propellants or sending electrical currents. They have embedded aligning aids. They make use of non-pyrotechnic release technologies, and reliable flyaway release of fluid and electrical connectors avoiding unnecessary damage to either the flight vehicle or the launch facility.
Mission Operations include several technology areas to improve operability. Examples:
Operations Control Center Simulator provides an end-to-end computer simulation environment for military space plane (MSP) or Orbital Space Plane (OSP) mission development. All elements will be simulated, including the launch vehicle, upper stages (both reusable and expendable), ground structure and payloads. The simulator incorporate hardware in the loop to demonstrate how actual hardware will react during simulated missions.
Advanced Control and Maintenance System drastically reduces the workload on the engineering and technician workforce and automates a tremendous amount of hidden manpower that directly supports the workforce.
Other examples: Enhanced Decision Models, Advanced Weather Instrumentation and Prediction Systems and Rapid Mission Planning and Simulation. The High Ops Tempo Ground Demo Test Bed will mature these technologies.
Range Operations can be either ground based or space based. Space based range architecture will provide a more flexible network of tracking and communication links enabling global launch operations. Improvements are also needed for the ground sensors and instrumentation to provide a more dynamic system with greater accuracy when the flight vehicles are near the earth's surface. Pay-offs will be improved reliability, safety, operability, responsiveness and affordability.

Payloads Technologies
Payloads can be both military and civilian (NASA and commercial). The MSP architecture can either be SMV (Space Maneuvering Vehicle) or MIS (Modular Insertion Stage). The CAV (Common Aero Vehicle) belongs in the ST Pillar and is not described here. Similarly, NASA's Orbital Space Plane (OSP) is also a payload for the launch system targeted by NAI, but is not a part of NAI.

MIS is an expendable upper stage intended to provide a very low cost, very responsive upper stage or insertion stage for small satellites, and for the CAV's launched from sub-orbital space operational vehicles (SOV's). It provides low cost modular composite construction and a very low cost engine/stage, and contains storable, cheap H_2O_2/kerosene propellants. SMV is a reusable upper stage and transfer vehicle intended to provide a low cost bus for space control and tactical ISR (Intelligence, Surveillance, Reconnaissance) satellites. It allows return of asset to earth for reuse and quick turn launch and operations when launched on RLV. It could also provide for short-term (< 1 year on orbit) satellite constellation fills for LEO & MEO orbit constellations. Table 5 lists the payloads goals for MIS and SMV.

SMV has many technologies common to RLV/SOV, including: TPS, IVHM, lightweight composite airframe, and avionics/flight control systems. Key technologies to be developed specifically for SMV are: a). Advanced reusable rocket technology – a high performance, non-toxic, highly reusable, 12,000 lbf engine that is highly operable (low cost) and uses peroxide tolerant propellant management device; b). Bi-propellant peroxide/JP8 throttlable RCS thruster that is high performance, does not affect MPS mixture ratio, and provides efficient on-orbit attitude control. Materials development is needed for liner-less, H_2O_2 compatible composite cryotank (for both SMV and MIS). It is planned to demonstrate SMV technologies in an SMV demo X-40B, which will be a follow on to X-37.

MIS will evolve from the current USFE (Upper Stage Flight Experiment) pressure fed engine into a higher performance pump fed engine. Technology effort will focus on reducing the structural mass and using the composite tanks thereby significantly improving the mass fraction through propellant tank design optimization. MIS will be demonstrated either on an ELV or a reusable demo vehicle such as X-42 (Reference 7).

Systems Engineering & Integration (SEI) and Integrated Vehicle Health Monitoring (IVHM)
SEI and IVHM are the soft technologies in the plan. They cover modeling and simulation, aero sciences and life cycle analysis. SEI allocates performance and reliability requirements on every system. IVHM levies sensing, data transmission and control requirements on every element of the system and monitors the health of the whole system. SEI/IVHM is not a requirement but will increase quality and reduce risk; it helps with technology prioritization as mission requirements and architectures change. SEI/IVHM activity is continuous over the life of the NAI and is not phased like the other hardware technologies.

Elements of SEI/IVHM (3rd tier) are: Aero-sciences, Life Cycle Analysis and Integration, Modeling and Simulation, and Element Health Management. Each area has several sub-elements. The approach, goals and objectives for each sub-element are given below.
Aero-sciences: Different sub-elements are described below.
Vehicle Aerodynamics includes flow physics modeling, aero-thermal-structural analysis, and aerodynamic and aero-heating databases.
Goals and Objectives: Enhanced vehicle performance margin, high fidelity concept design and analysis with decreased cycle time, reduced ground testing requirements in development cycles
Propulsion-Airframe Integration sub-element includes tip-to-tail air-breathing and combined cycle, and flow path and vehicle integration, Analysis methods and test techniques to assess aero-propulsive performance, stability and control through-out ascent and reentry trajectories, experimental and analytic aero-propulsive databases for reference concepts.
Goals and Objectives: Enhanced vehicle performance margin, higher fidelity concept design and analysis with decreased cycle times
Loads and Structural design sub-element includes – safety and reliability; damage tolerance, durability & residual strength; structural analysis, structural dynamics, thermal-structural analysis and materials modeling tools; demonstration of damage tolerant designs, integrated aero-thermal structural-thermal design tools, thermal acoustic design tool and reliability-based analysis and design.
Goals and Objectives: Increase safety and reliability, reduce cost, reduce turn time (to < 5days), reduce structural weight (by > 5%), verify design and analysis tools, and increase discipline integration
Guidance, Navigation and Control includes advanced GN&C using robust, adaptive, and intelligent algorithms.
Goals/Objectives: Enhancements in vehicle performance and safety margins, and robustness to handle off-nominal flight situations

Life Cycle Analysis and Integration: Different sub-elements are described below.
System-level Design Environment includes development of integrated engineering environment (IEE) that support distributed RLV analysis and assessments, total life-cycle analysis and assessment capability that progresses from a conceptual level of fidelity to a detailed level.
Goals/Objectives: Decreased analysis cycle and design rework times with increased levels of analytical fidelity, complete life cycle analyzed at each step, known uncertainties through each step of life cycle, increased fidelity of analysis earlier in the system life cycle, and central parametric geometry model driving performance and process-based analysis
RM&S, Cost, Operations and Safety tools includes root cause analysis of existing launch procedures, analysis evolution beyond existing parametric and existing order models, failure modes and effects analysis (FMEA) tools, probabilistic risk assessment tools, ground facilities and infrastructure design tools, visualization capabilities, activity-/process based cost estimation, level 1 tools for RM&S and cost.
Goals & Objectives: Operations assessment and process model, increased fidelity in ground infrastructure design and cost estimation, decreasing uncertainty in cost estimates through life cycle, technology planning and development based on rigorous and early FMEA, visualization of ground process early in life cycle
IVHM Architecture and Software includes integration of IVHM and flight control functions, definition system-level failure modes, co-ordination/allocation of sensor requirements for all subsystems, and development of virtual test bed for integration, demonstration and evaluation of subsystem and system HM technologies
Goals & Objectives: Improve overall launch system reliability (MTBF -- >3000 hrs. Crit 1 failures -- <1 in 200 launches, false alarm rate -- <1 in 200 sorties); reduce vehicle maintenance cost; increase operability (reduce turn-around time to 7 days, airframe life – 100 flights)
Modeling and Simulation: Different sub-elements are described below.
Rapid Mission Planning includes pre-characterization of missions for bounds of the containerized payloads specification and impact of weather and development of modular mission planning tools
Goals & Objectives: Reduce mission planning time (1 hour for containerized payload and one shift for unique payloads), reduce mission sensitivity to weather.
Operations Control Center Simulation includes complete flight ops simulation (launch to landing, different type of vehicles) and development of modular simulation tools
Goals & Objectives: Reduce MSP flight ops crew size, reduce mission control size and assess alternate missions and vehicles
Ground Processing Simulation includes complete ground ops simulation (landing to launch) and development of modular simulation tools
Goals & Objectives: Reduce MSP call up and turn-around times, increase MSP alert-hold times and reduce ground-processing cost.
Element Health Management: Different sub-elements are described below.
Structural Health Management includes definition of structural system failure modes, characterization of symptoms of structural degradation, rapid evolution of fiber optic technologies.
Goals & Objectives: Improve structural reliability and reduce structure-related maintenance cost through informed maintenance (e.g., predict remaining component life through performance based diagnostics)
Vehicle Subsystems Health Management includes power generation & distribution, actuator/control effectors, avionics/command & telemetry, wireless sensors, multi-sensor packaging.
Approach: Define flight subsystems failure modes, Characterize symptoms of component degradation
Goals & Objectives: Improve flight subsystem reliability, Reduce flight subsystem maintenance cost through informed maintenance
Ground System Health Management includes definition of flight subsystem failure modes, Identification of existing HM technologies and determination of transition requirements for use on ground systems, Determination of critical failure modes and definition of technology needs for detection and mitigation
Goals & Objectives: Improve ground system availability for launch and mission support, facilitate rapid maintenance through accurate fault isolation, improve ground system safety
Propulsion System Health Management includes definition of propulsion system failure modes, characterization of symptoms of component degradation
Goals & Objective: Improve propulsion system reliability; reduce propulsion system maintenance cost through informed maintenance.

Technology Demonstrations

Technology demonstrations are necessary for technology validation/maturation. They can either be ground-base or flight demos. The goal is to maturate the technologies to TRL-6, which often means validation through flight tests in some cases. Many technology demonstrators are envisioned and their approaches, goals and objectives are briefly stated in Table 6. Ops demonstrator provides technology on-ramps for integration and test. All technologies (airframe, payloads, flight critical subsystems, propulsion, operations) can be tested using this type of demonstrators. Flight experiments/tests are generally much more expensive than ground base tests and care will be taken to minimize the number of such experiments. Flight experiments will be run only if ground base tests will not do the job. While many of the high HSH experiments tend to be flight experiments, many of the rocket propulsion tests will be ground based. Space access demos are in the planning stage and various concepts are being evaluated. Prioritization will be made based on system engineering studies and value stream analysis.

Implementation of NAI

A unique management structure was developed to implement the NAI. A synergy group was created consisting of members from various DOD agencies and services and NASA. NASA, Services and DOD agencies have separate budgets, and will continue to have control over their budgets when managing NAI. The challenge is to maintain autonomy while keeping the partnership commitments. Hence, coordination is required for planning, advocacy, budget and conflict resolution. A centralized execution and oversight office has been created for the purpose. Details of this office with its roles and responsibilities may be found in reference 8. Execution of NAI will be distributed, with each service/agency managing own projects. Partnership terms will be defined for each project in a memorandum of agreement (MOA), signed by the highest executing authorities in the agencies involved. Progress will be reviewed periodically by a steering group, which sets priorities for projects. A board of directors (currently the Space Partnership Council) will provide the general direction for the NAI and approve the top-level roadmaps.

Participation by the Industry and Universities

NAI technology planning and roadmap information was shared with the aerospace industry and the academia. A briefing for industry on the Space Access pillar was held in June 2002. Industry feedback was solicited and was very positive and stressed the need for a requirements-guided NAI program, which is reflected in the current plan. Industry also recommended a continued, strong NASA-DOD partnership. A major portion of the technology development and demonstration work is likely to be performed by the industry. Universities will also be engaged in the NAI by doing advanced research and developing the skilled personnel needed for implementing the NAI.

Summary

A comprehensive technology plan has been developed for a responsive space access – a major pillar of the NAI. The main elements of the plan are airframe, propulsion, flight subsystems, operations, payloads, systems engineering and integration, integrated vehicle health monitoring and technology demonstrations. The main goals of these technologies are to improve operability, reduce cost, improve safety, reliability, life and performance, and reduce turn time. A phased approach to achieving these goals was developed through teamwork among NASA, Tri-Services and other DOD agencies. The technologies will be maturated to TRL-6 through ground base and flight demonstrations, and transitioned into development or acquisition programs for the next generation launch vehicles for space access.

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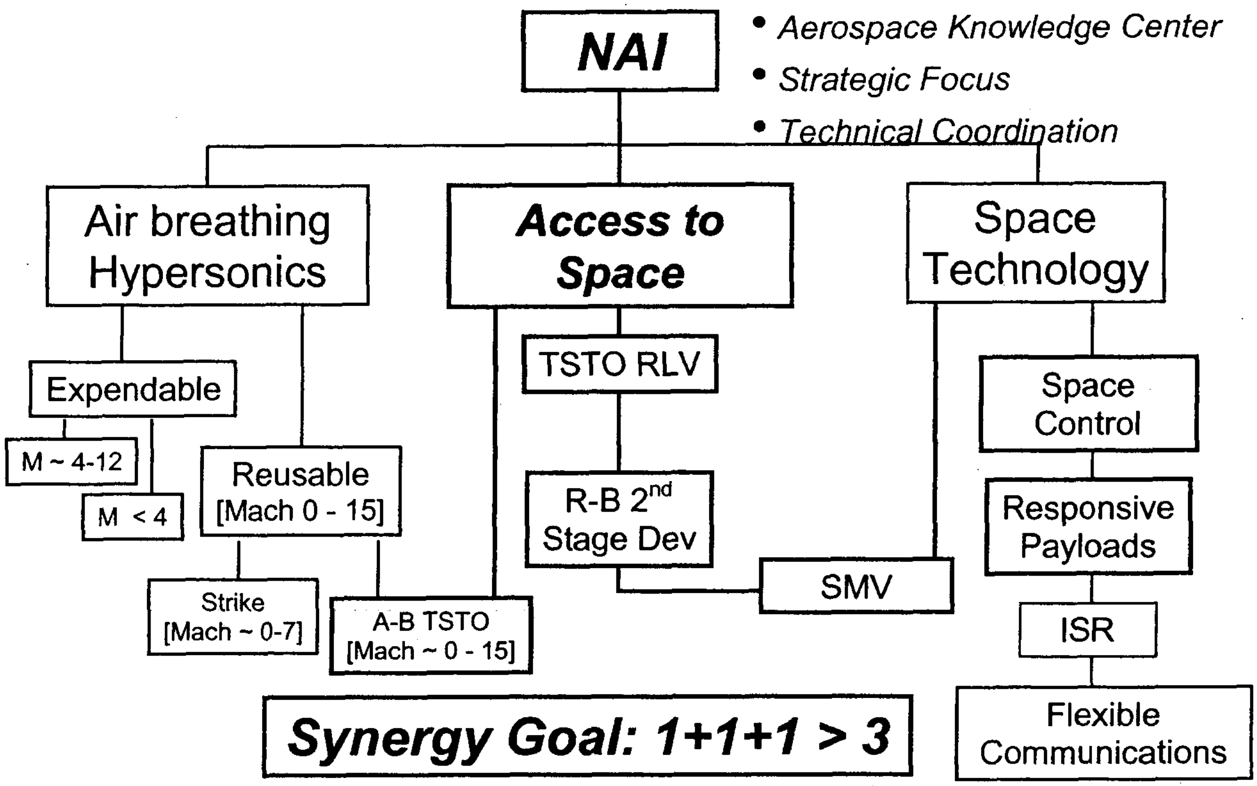

Figure 1: National Aerospace Initiative – Access to Space Technology Framework

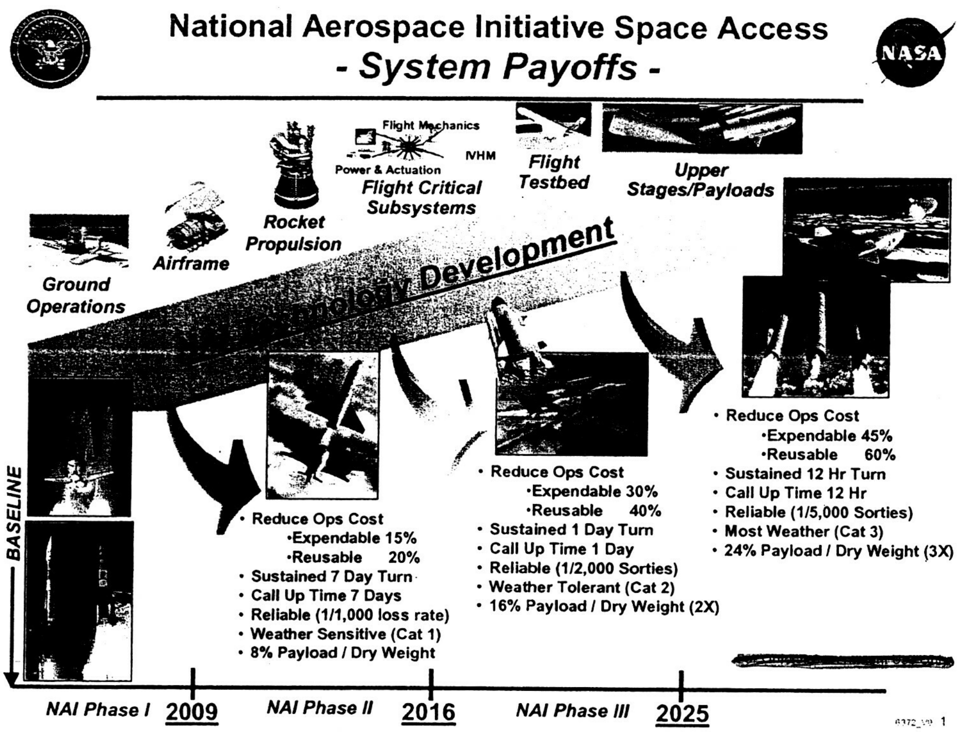

Figure 2: NAI Access to Space technology products and pay-offs in three phases (notional).

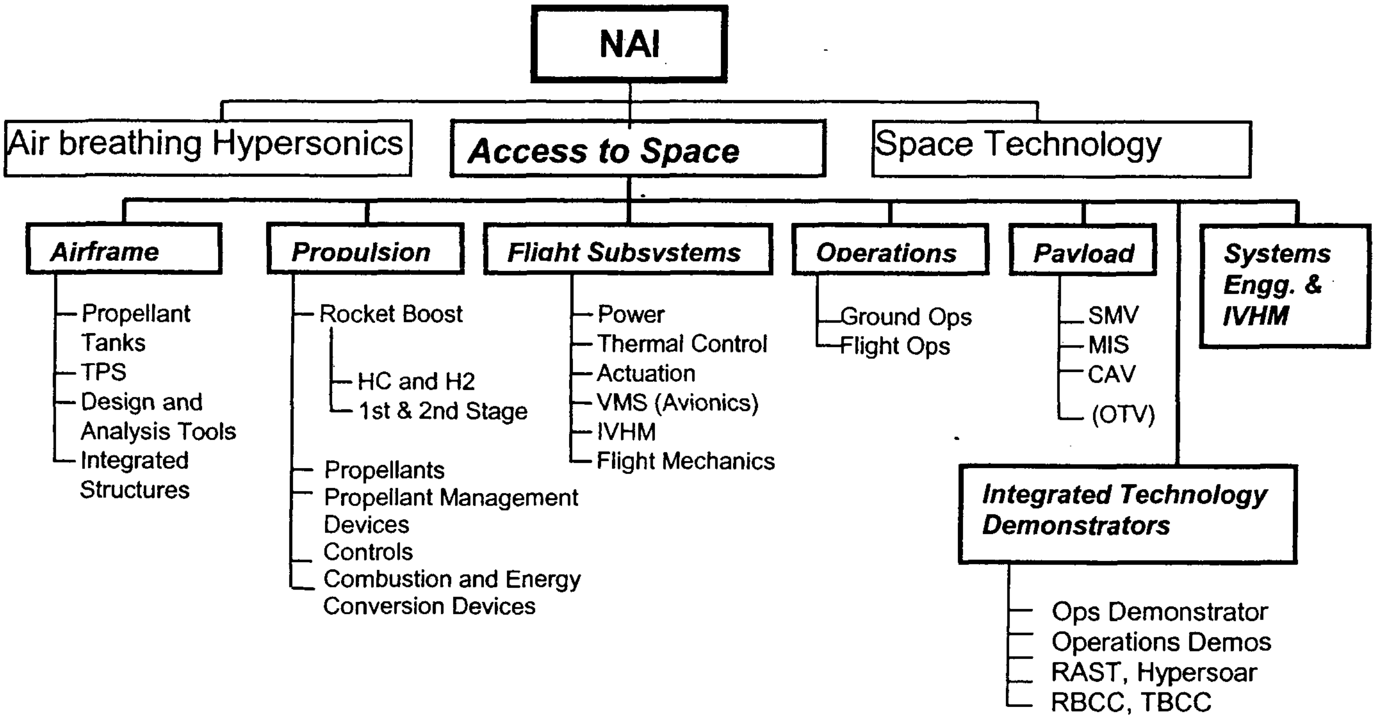

Figure 3: ATS Taxonomy – Subsystem Areas and Components

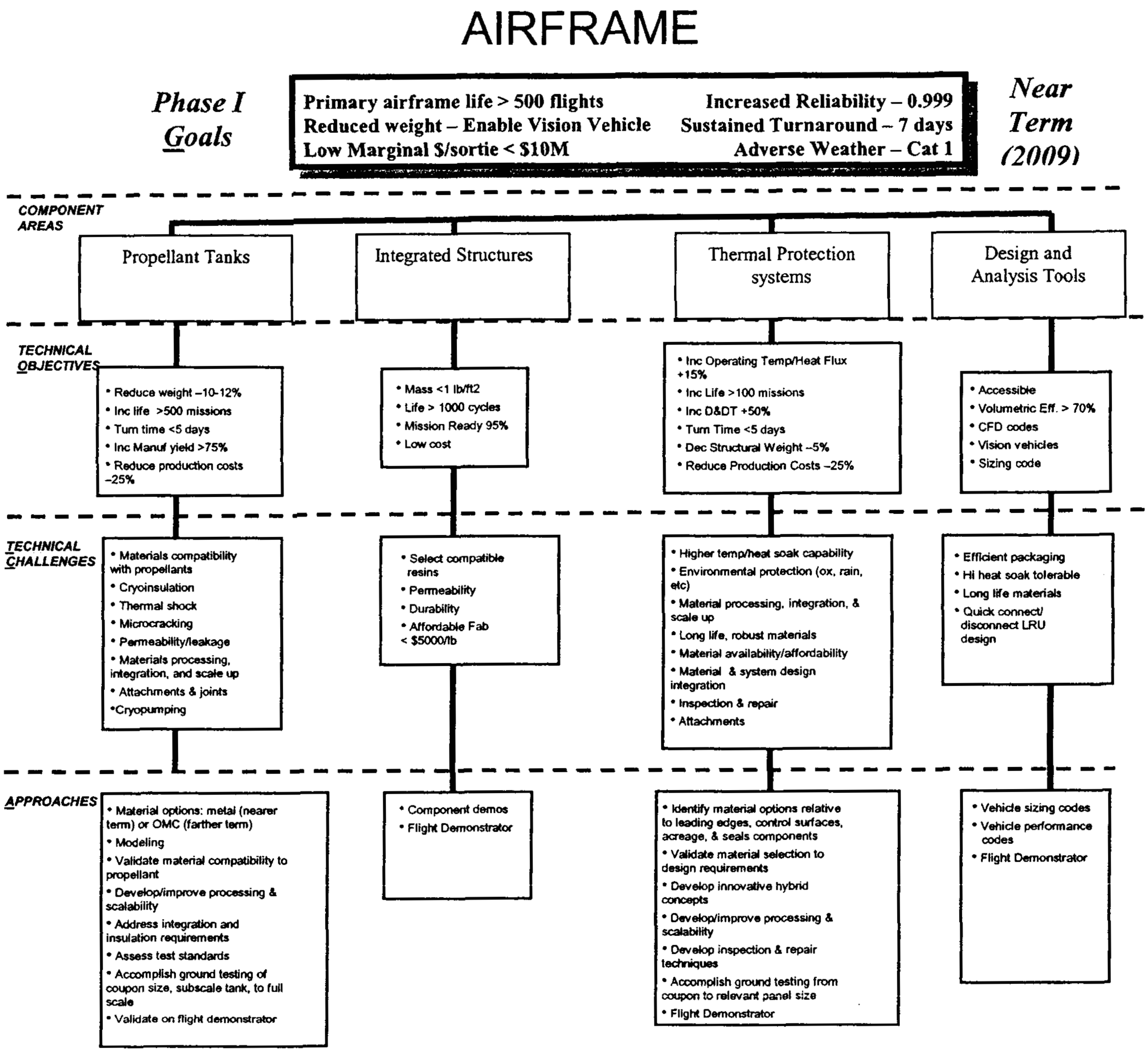

Figure 4: An example of the GOTCHA process used for technology planning

Table 1: **Airframe Technology Goals**

Objectives	Baseline (Shuttle)	Phase I Goal	Phase II Goal
General			
Airframe Life	100 missions	250 missions	500 missions
Weather Tolerance	Category 0	Category 1	Category 2
Payload/Airframe weight	16%	20%	24%
TPS MMH/sortie	100,000	2,000	100
Integrated Structures			
Life	1 mission	250 sortie	500 sortie
Turn time	60 days+	5 days	1 day
Production cost	TBD	-25%	-35%
Cryogenic Tanks- Composites			
Life	1 mission	150 missions	250 missions
Turn time	N/A	5 days	1 day
Reduce weight*	~1 lb/ft3	- 10%	- 25%
Production cost	SOA	- 25%	- 35%
Manufacturing Yield	SOA	+ 15%	+ 25%
Cryogenic Tanks - Metallic			
Life	1 mission	150 missions	250 missions
Turn time	60 days	5 days	1 day
Reduce weight*	~1 lb/ft3	- 10%	- 25%
Production cost	TBD	- 25%	- 35%
Manufacturing Yield	TBD	+ 75%	+ 85%
TPS			
Temperature – leading edge	3000F	3450F	3800F
- Control surfaces	2400F	2800F	2800F
- Acreage	2300F	2400F	2500F
- Acreage Leeward	700 – 1200F	1500F	1800F
Life	RCC/Tiles 33/100 flights	100 missions	200 missions
Turn time	50 days	5 days	1 day
Weight	RCC/Tiles/AFRSI	- 5%	- 15%
Production cost	RCC/Tiles/AFRSI $12K/1.16K/0.33K per ft2	- 25%	- 30%
Seals			
Operating temp/heat flux		+15%	
Life		> 100 missions	
D&DT		+50%	
Turn time		< 5 days	
Structural weight		-5%	
Production cost		-25%	
Configuration Analysis Goals			
Reduced design cycle time	Shuttle – 6 mo NASP – 2 weeks Today – 4 days	75% reduction	
Improved Analysis (1st order) accuracy	Tools dependent mass properties ~ 30% Trajectory – 10% Aero thermal ~ 50%	5-10% across all tools	
Traceability to vision vehicles	Demonstrate traceability to weight optimized TSTO rocket	Demonstrate traceability to all space access vision vehicles	

Highly Operable Configuration Goals			
Reduced sonic boom overpressure	Shuttle – 1.25 psf	< 1 psf at 60,000 ft	
Reduced aerodynamic heating rate	Shuttle	10% reduction	
Reduced aerodynamic heat soak	Shuttle	40% reduction	
TPS percentage of orbiter weight	16% (OV 103, circa 1995)	13% (20% reduction)	
Simplify landing for VTOL concept	Propulsion rotation on DC-X	Aerodynamic rotation 40% less propellant use, 10% lower dry weight versus VTHL	

Table 2A: **Propulsion subsystem goals**

System Attributes	**Propulsion Goals/Metrics**
Sortie utilization rate	Operations cost. Failure rate, engine life
System Availability	Failure arte, Engine life
Flight safety	Failure rate, Engine life, operations cost
Performance and payload weight	ISP, thrust to weight ratio
Cross range & take-off and landing	Thrust to weight ratio
Alert hold	Operations cost, failure rate
Design life	Acquisition cost, operations cost, thrust to weight, failure rate, engine life
Maintenance man hours per sortie	Operations cost, failure rate, engine life

Table 2B: **Propulsion component taxonomy objectives**

Propellants	Propellant Management Devices	Combustion and energy conversion Devices	Control systems
Increase propellant energy	Decrease component weight Reduce component cost Increase component reliability	Decrease component weight Reduce component cost Increase Isp and Isp efficiency Decrease part count	Decrease component weight Reduce component cost

Table 2C: **Rocket propulsion system goals**

Engine Type	**Goals/Metric**	**Baseline**	**Phase 1 Goals**	**Phase 2 Goals**	**Phase 3 Goals**
Cryo boost (LH2)					
	Isp (trajectory average)	435.5 (SSME)	1% (439.9)	2%	3%
	Thrust to weight (Trajectory average)	66.7	30% (86.7)		
	Hardware cost	$40 M (SSME)	-15%	-25%	-35%
	Support cost	$1.9M/engine/flight	-15%	-25%	-35%
	Failure rate	0.002	-25% (0.0015)	-50%	-75%
	MTBR	<5	20	60	100
Hydrocarbon Boost					
	Isp (seconds) Sea level/vacuum	288.7 (avg.) 263.6/295	+13% (326.6) 297.9/333.4	+15% (332.0) 303.1/339.3	+17%
	Hardware Cost	SSME baseline ($40M)	-15%	-25%	-35%
	Failure rate	0.002 – SSME baseline	-25% (0.0015)	-50% (0.001)	-75%
	MTBR	1	20	60	100

Table 3: **Flight subsystem goals for Phase I & II**

Metrics	Baseline Shuttle 2000	Phase I Goals	Phase II Goals
Mean Time Between Component Failures	<1500 hours	>3000 hours	>7500 hours
Catastrophic failures	1 in 250 launches	1 in 2000 launches	1 in 5000 launches
Reduce weight	45,000 lbs	Reduce 10%	Reduce 20%
Reduce turn time	80 days	7 days	1 day
Launch life	1 launch	100 launches	250 launches
Number of maintenance staff	100's	20's	10
Marginal flight subsystem cost per sortie	$ Millions	$ 10,000's	$ 1000's

Table 4: **Operations Technology Thrust Areas and Goals for Phase I & II**

Thrust Areas	**Baseline (STS)**	**Phase I Goals**	**Phase II Goals**
Propellant Management	3 hours	2 hours	1 hour
System assembly	~ 4 months	24 hours	1 hour
Launch pad operations	2 – 3 weeks	24 hours	4 hours
System refurbishment	100K MM hours	7500 MM hours	1200 MM hours
Mission operations	100s of people	30 people	15 people
Range reconfiguration	48 hours	24 hours	12 hours

Table 5: **Payloads Goals for Phase I & II (Military)**

Payload	**Goals**	**Baseline system**	**Phase I Goals**	**Phase II Goals**	**Phase III Goals**
MIS	Isp, sec	275 (USFE)	275	310	320
	Mass Fraction	0.46 (USFE)	0.8	0.85	0.9
	Stage Cost	$66.5M (Centaur) $35M (IUS)	< $1M	< $800,000	<600,000
	Engine cost	$ 10.5M (RL10) $3.7M (Delta II 3rd stage)	<$500,000	<$400,000	<300,000
	Responsiveness	30 days (EELV)	<1 day		---
SMV	Isp, sec	246 (X-37)	315	320	330
	On-	998 fps (STS) 2600 (X-37)	6500 fps	9000 fps (GTO access)	10,500 fps
	Mass Fraction	0.3 (X-37)	0.55	0.65	0.7
	Thrust	3300 lbf (X-37)	12,000 lbf	---	
	Throttling	Unable (X-37)	50%/33%	50%/25%	
	Sortie Cost	$? (X-37)	< $1M	< $1M	

Table 6: **Key Flight Demonstrations**

Flight Demonstration	**Approach**	**Goals/Objectives**	**Pay-offs**
Ops Demonstrator (Mach 10+)	Build subscale flight test vehicle, scale up to future RLVs	Flight demo, Mach 10 Turnaround <7 days	Demonstrate MSP technologies to TRL-6, Demonstrate aircraft-like operations
RAST – hypersonic test bed	Sub orbital test at Mach 10-15	Validate propulsion cycles and MSP payloads, Pop-up small payloads to LEO	Orbital test of ISR sensors (small payloads, ~1000lbs)
Operations demonstrations	Operations technologies, integrated with flight demo	Demonstrate operability in flight conditions	Achieve TRL-6
Flight critical subsystems – flight demonstrations	Flight subsystems technologies, integrated with flight demo, e.g., RAST; demonstrate vehicle controllability & vehicle ops	Demonstrate reliability and operability of subsystems in flight conditions, reduce weight and cost, improve operability	Achieve TRL-6, low cost, high reliability & lower weight
Flight technology experiment demonstrations	Use recoverable vehicles—existing options: NASA or military aircraft, TERV (Technology Experiment Reentry Vehicle, mounted on an ELV), or ESA EXPERT	Internal experiments – GPS/INS, IVHM, GNC, Power supplies, Advanced Avionics, Sensors, actuators External experiments – TPS Acreage, Leading edge, thermal barriers and seals, aero science experiments	Demonstrated technologies, transition opportunities
Technology Experiment Platform Opportunities	Manifest/integrate technology experiments on NASA/DoD recoverable launch vehicles—aircraft, shuttle and other platforms	Provide timely and cost effective means of advancing technologies to TRL-6	
Space Maneuver Vehicle (SMV) Demo: X-40B	X-37 based X-40B SMV with improvements (e.g., ARRE), multiple launch options	Responsiveness (access to all LEO, MEO, GTO orbits), safety, operability, affordability and flexibility (multiple payloads to support ISR, space control)	
MIS demo	USFE demo USFE follow-on	Lower cost, improve safety and operability and fill need for various satellites	
High Tempo Operability Experiment	Apply aircraft HARV technology to MSP via wind tunnel tests, CFD/ flight demo	Reduce hypersonic heating, mitigate sonic boom and reduce reentry overpressure, reduce ops cost, VTOL- minimal facilities (land anywhere), reduce re	
Integrated Stage Demonstrator (Hypersonic test bed)	Build flight test vehicle, Significant residual capability, multiple options (e.g., common 2nd stage or 1st stage)	Flight up to Mach 18. Turnaround <7 days High reliability (>0.998) Low marginal cost	Demo full scale MSP technologies, Significant residual capability
Hypersoar Air breathing Demo Vehicle	Fully reusable small demo, Launch from small sounding rocket or RAST, Low Q release, Glide to test conditions	Small and simple, Supports multiple concepts, Gathers critical Isp data	Demonstration at subscale and low cost